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PROBLEMS OF FRUIT TREE NUTRITION

POSSIBLE LINES OF APPROACH

by

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CONTENTS

	PAGE
FOREWORD	I-2
THE NUTRITION OF WOODY PLANTS WITH SPECIAL REFERENCE TO CULTIVATED FRUIT PLANTS ..	
MANURING OF FRUIT PLANTATIONS AND ORCHARDS ..	

FOREWORD.

DURING the last three years we have received requests from all parts of the Empire for a synopsis of the progress of experimental work on the nutrition of fruit trees and for information on the practical problems of manuring.

A synopsis such as the section on Nutrition in *Fundamentals of Fruit Production** illustrates the many different angles from which the subject has been approached and the immense amount of investigation that had already been put into it up to some ten years ago. We have, moreover, by request translated in full that most recent Russian synopsis of Antoshin on orchard and small fruit manuring.** But this, whilst reviewing in detail and grouping under various fruits the many empirical and experimental results achieved, does not give any direct lead as to the development of general principles.

A journey around many of the fruit-growing areas of the New World in 1930-31 made it abundantly clear that investigators were looking for methods of research likely to bring them fairly rapid results, yet based on generally applicable principles, by which they might unravel the problems which in established orchards so urgently needed solution.

The only line of approach which would appear to satisfy the immediate wants of these investigators is that worked out with such pre-eminent success in England by Dr. T. Wallace, Long Ashton Research Station, University of Bristol.

The method consists of studying the effects of deficiencies of the elements essential for nutrition by using the plant itself as a biological indicator. Observation of external characters, correlated with ash analyses, has made it possible to determine, for example, the leaf symptoms which are associated with deficiencies of certain elements, and Wallace has been able to establish a system whereby such deficiencies can be diagnosed by direct observation in the field.

The value of information obtained by ash analysis is not to be discounted, but the direct method places a most valuable weapon at the disposal of the pomologist, who, having neither the time nor the facilities for chemical investigation, nevertheless finds it necessary to be able to detect changes in the balance of mineral economy within the plant.

Although, presumably, the symptoms in the plant by which it is possible to diagnose deficiencies may vary from one part of the fruit-growing world to another owing to climatic conditions, just as the deficiencies themselves vary in different soils, *e.g.*, the deficiencies of potash in England, of nitrogen in the U.S.A., and phosphatic deficiencies in the South Island of New Zealand, it is apparent that abnormal

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* *The Fundamentals of Fruit Production.* Gardner, V. R., Bradford, F. C., and Hooker, H. D., Mograw Hill, New York, 1922.

** *Experimental Data on Orchard and Small Fruit Manuring.* S. T. Antoshin. *Transactions of the Scientific Institute on Fertilizers,* No. 81, 1931.

symptoms in foliage and growth characters of apple trees, for instance, are fairly widespread. Such symptoms are, indeed, not identical with those established for this country. They do, however, strongly resemble them, and appear likely to prove mere modifications due to environmental conditions.

Whilst the most accurately conducted field trial, essential as it is as a supplement, could by itself but reveal the advantages of particular applications under a given set of conditions, as in the dramatic results obtained by Rigg on phosphate-deficient soils, the establishment of deficiency symptoms for a series of horticultural plants under known climatic conditions must still be the complementary method of interpreting such trials and giving them a far wider application than would otherwise be possible. Again, the study of the carbohydrate-nitrogen ratio, whilst proving a most welcome stimulus to further research for fundamental principles, has resulted in such a divergence of practical advice that any general application along economic lines still remains elusive.

During the past year Dr. Wallace published two papers of a very different nature, one, *The Nutrition of Woody Plants*,* setting out very clearly the general principles along which he had worked, the other, *Manuring of Fruit Plantations and Orchards*,** showing the possibilities for giving general advice to fruit growers which these investigations have opened up.

Whilst both the journals in which these articles appeared have a wide circulation, it is doubtful whether they would be readily available to the numerous investigators interested in this particular subject throughout the Empire. The Bureau therefore obtained both the consent of Dr. Wallace and the permission of the journals to reprint the two articles together, so as to bring into the greatest prominence this line of investigation which would apparently be just as widely and rapidly productive of practical results elsewhere as it has been in this country. It may be noted that work along parallel lines has already been initiated both in Canada and Australia.

In addition, after consultation with Dr. Wallace, the Bureau has decided to issue in stencilled form (1) Occasional Paper 1, setting out in detail Dr. Wallace's most improved method of technique and (2) Occasional Paper 2, a short *resumé* of the contents of Antoshin's bulletin,*** together with a translation of his conclusions and of his appendix dealing with the lay-out of manurial trials in the U.S.S.R. Finally, it is intended to issue later, probably in printed form, an indexed bibliography of the most important written work on the nutrition of fruit trees, with short abstracts of each. With regard to the bibliography we would ask readers to help by sending us information as to publications known to themselves which contain important articles on orchard manuring and, if they have not already done so, reprints of their own on the subject.

We cannot end without thanking Dr. Wallace most heartily for permission to re-issue his articles and for his greatly valued co-operation and help.

R. G. HATTON.

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* *The Nutrition of Woody Plants, with Special Reference to Cultivated Fruit Plants. Forestry*, 1932, Vol. VI, pp. 10—26.

** *Manuring of Fruit Plantations and Orchards. J. Roy, Agr. Soc.*, 1931, Vol. 92, pp. 18.

*** The full translation is available at the Bureau.

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THE NUTRITION OF WOODY PLANTS

(WITH SPECIAL REFERENCE TO CULTIVATED FRUIT PLANTS)

BY T. WALLACE

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INTRODUCTION

THE ultimate practical object in nutritional investigations of fruit plants is to discover methods of controlling the growth processes which determine the yields and qualities of the fruits borne by the various types of plants utilized in fruit-growing. The fruit tree has no value to the fruit-grower other than as a medium for producing fruit, hence the value of any given tree is measured in terms of the value of the crops which it is capable of yielding. For this reason the general outlook of the research worker on nutritional problems of fruit trees must differ somewhat from that of the forestry expert whose main object is timber production, but nevertheless the problems in the two instances necessarily provide points of common scientific interest. Thus, although in one case the major practical object is fruit and in the other it is timber, the fundamental scientific problems involved relate to the growth processes of the trees.

The production of crops of fruits with definite qualities, and of timber with specific properties, are merely expressions of the particular nutritional conditions of the various trees concerned, and to understand either it is essential to study the many and varied problems relating to general nutritional processes. The common problem may be stated as 'The growth responses of woody plants to various environmental conditions over relatively long periods of years'.

The more important broad differences which occur in the two cases may be stated as follows:

Fruit plants have been evolved primarily for qualities relating to fruitfulness, whereas forest trees have been selected for timber production. In the former instance, crops are removed periodically during the growth period, and in the latter products are not usually obtained during the growth periods of the trees.

Fruit plants in general occupy more favourable growth sites than forest trees: soil conditions are generally selected as being especially favourable to tree growth. In the case of forest sites the land utilized is usually of the type regarded as of low value for agricultural crops, and the situations are frequently such that the trees are exposed to very unfavourable climatic conditions.

The systems of management of fruit plants are much more intensive than those applied to forest trees: cultivation is carefully adjusted to meet particular requirements, and is varied from time to time; manuring is regularly practised, often at a high level; pruning is systematically carried out and frequently in

a most detailed way; and pests and diseases are combated by most elaborate seasonal spraying programmes.

The management applied to forest trees must necessarily be much simpler, and thus fluctuations in nutritional conditions in forest trees over the growth period, due to management factors, are likely to be less than those which occur in fruit trees over the life-history of a well-managed fruit plantation.

In both instances the nutritional conditions which exist within the trees are the resultant of the intrinsic properties of the materials planted and the environmental conditions which are operative on the plants over the growth histories.

In the case of fruit plants the more important factors which determine the nutritional conditions at any time may be grouped as follows:

(*a*) Materials—including the classes of fruit, varieties, rootstocks in the case of the majorities of tree fruits, and the age of the plant.

(*b*) Environmental factors—these may be divided into two subgroups.

1. Natural conditions—including the climatic factors of rainfall, temperature, sunshine, &c.; soil factors—embracing chemical, physical, and biological properties; parasitic organisms—pests, fungi, &c.
2. Management factors. These include soil treatment—cultural operations and manuring; control of pests, fungal and bacterial organisms, &c.; manual operations on the tree, such as branch-pruning, fruit-thinning, bark-ringing, &c.

The effects which may result in particular instances from these factors may be illustrated by the following facts which have been elucidated during the course of investigations at Long Ashton.

Plums and black currants as classes yield the best results under 'high' nitrogen conditions; apples, gooseberries, and red currants usually fail under 'low' potassium feeding; varieties and rootstocks exhibit marked differences in resistance to unfavourable nutritional conditions; old trees require 'high' nitrogen feeding; high rainfall during the growing season produces effects similar to high nitrogen feeding, and dry soil conditions tend to counteract high rainfall effects; grass systems of culture induce low nitrogen conditions within the trees, and tend to reduce effects due to low soil potassium; pruning may produce growth responses similar to manurial effects; management factors may greatly alter disease problems by affecting the susceptibility of the plant or by ensuring freedom from attacks of pests or organisms.

The foregoing statements will suffice to show the similarities and differences which are likely to occur in investigating nutritional problems relating to fruit trees and forest trees.

The present paper has been written primarily with the view of bringing to the notice of workers interested in problems of the nutrition of forest trees the results of nutritional investigations on fruit trees which have been carried out by the writer at Long Ashton Research Station since 1920. In order that

readers may also become acquainted with other investigations in the subject, a brief outline of previous and contemporary work is also included.

HISTORICAL

Previous to 1920, by far the greatest proportion of investigations relating to the nutrition of fruit trees had been carried out in the U.S.A. In this country the only extensive experiments up to that time were those of Bedford and Pickering at Woburn (7), and of Dyer and Shrivell at Hadlow, Kent (10). In European countries no sustained investigations appear to have been conducted prior to the above date, although numerous references appear in the literature of minor investigations, and especially in connexion with pathological conditions arising from defective nutrition. (See references in papers 45, 48, 51.)

The older experiments both in the U.S.A. and in this country consisted almost wholly of field experiments, modelled after the pattern of the classical experiments on agricultural crops instituted at Rothamsted by Lawes and Gilbert, in which it was usual to test the effects of various manurial treatments, such as dressings of dung, complete fertilizers containing nitrogen, phosphorus, and potassium and complete fertilizers less nitrogen, phosphorus, and potassium respectively against control treatments where manurial dressings were completely withheld. In the U.S.A., after 30 years of experimenting along these lines, it was realized that the results obtained were extremely small in proportion to the time, energy, and expense involved, and it became generally accepted that the field experiment method, as previously used, was not likely to lead to the acquisition of much knowledge of the nutritional problems of fruit trees. The more important of these older investigations have been previously discussed by the writer (40), hence in the present instance it will suffice to draw attention to the salient points which appeared to emerge from the work.

W. H. Alderman (2), in a paper entitled 'The Status of Orchard Fertilization Experimentation' delivered before the American Society for Horticultural Science in 1919, summarized the results obtained during the previous 30 years, and stressed the inadequacy of the field experiment method as practised to throw light on the problems of fruit-tree nutrition. He stated the position reached as follows: 'This seems to be a suitable occasion to pause and consider the work that has been accomplished to date. Within the past two years a number of well conducted experiments extending over long terms of years have matured, and the results been made public. So much has been written on the subject that it is a bit difficult to summarise the case, since the evidence does not all point in the same direction. It is somewhat simpler if we first confine ourselves to the points over which there is seemingly no contention.

> '1st. There are apparently a great many orchards growing upon a wide variety of soils that will not respond economically to the application of any form of commercial fertilizer, nor of manure. This fact is well established by the work in New York, New Hampshire, Maine, West Virginia, and other states.

'2nd. Orchards are much more likely to respond favourably if they are given sod mulch treatment than if kept under cultivation. A comparison of the work in the above mentioned States with that in Massachusetts and Ohio, furnish interesting evidence upon this point, as does also the work in Pennsylvania where the three sod orchards displayed considerably greater gains than the three under cultivation.

'3rd. Orchards under starvation conditions usually give a ready response to fertilisation when other treatments (culture, pruning, spraying, etc.) remain unaltered. This is well demonstrated by some of the Ohio, Oregon, and West Virginia experiments.

'4th. Nitrogen in a readily available form seems to be the only element of plant food that is uniformly a factor in the favourable responses—when such are secured.

'These four points, apparently, are about the only outstanding, uncontested results of our orchard fertiliser experiments, conducted over a period of thirty years or more by twenty-eight different experiment stations. This information is of no small value to the orchard industry, and has been well worth working for, but the investigator who is seeking to understand the "how" and "why" of the reactions finds only disappointment. There have been those among us who have thought and talked of principles that underlie orchard fertilisation, but so far no principles have been formulated which are capable of application. There are others—probably the majority—who have maintained that orchard fertilisation cannot be reduced to general principles having a wide application. So far this group has not been disappointed.'

Two experimental centres were utilized at Woburn (7), one on a heavy soil at Ridgmont and the other on a light sandy soil at Millbrook. At Ridgmont no significant effects, either on the growth or fruiting of apple trees were obtained from dung or fertilizers, although on the same plots bush fruits, nursery stock, and vegetables responded to the treatments. Pickering accepted this result as a likely one for fairly fertile soils of the Ridgmont class. On the light sandy soil at Millbrook apple trees and gooseberries responded to dressings of dung and fertilizers, provided the latter contained potash. At Hadlow (10) the outstanding result was the action of potash fertilizers for all classes of fruits, although the soil was of heavy texture.

Since 1920 nutritional problems on fruit trees have been approached from a new angle in the U.S.A., chiefly owing to the comparative failure of the previous work, and to the stimulating carbohydrate/nitrogen theory of Kraus and Kraybill (26). This hypothesis has served to focus attention on the interrelated conditions of growth and fruitfulness, and attempts have been made to interpret nutritional conditions in terms of carbohydrate/nitrogen ratio. Following these lines attempts have been made to analyse the chemical factors associated with shoot-growth responses, fruitfulness and unfruitful conditions, blossom-bud formation, fruit set and biennial bearing, and no field experiment is now considered complete without parallel chemical and physiological investigations. Published papers relating to these investigations are extremely

numerous, and for an introduction to the literature the following books and journals should be consulted (3, 8, 11).

A second phase of modern field experiment work requires mention, namely, the application of statistical methods, and reference to the above-mentioned publications will provide numerous examples of typical studies of this kind.

These further investigations have continued to demonstrate the importance of nitrogen for fruit trees under U.S.A. conditions. There is still no clear evidence that phosphatic manuring produces direct responses in fruit trees, though in several instances it has been shown that indirect effects may follow from the application of phosphates by stimulating the growth of leguminous cover-crops (5). Potash has only been shown to be a problem in one or two isolated instances, the most important being a case of prunes, studied by Hoagland (21) and his associates in California, a further instance being one under investigation by Shaw in New Hampshire (35). Of other field problems, certain relating to pathological conditions require mention, viz. lime-induced chlorosis associated with iron deficiency (23, 28), mottle leaf of citrus (16, 17, 18, 24), boron toxicity (25), and rosette of apples and pecans (29, 30). The investigations of Veihmeyer (38, 39) and his associates, relating to problems of soil moisture supply and irrigation practice in connexion with fruit-tree nutrition, also form important contributions.

Haas (15, 33) and his co-workers have been pioneers of intensive laboratory and pot studies on citrus and other trees in the U.S.A., and have made important advances in the knowledge of the action of mineral elements in tree nutrition.

In this country, in addition to the nutritional work at Long Ashton, several manurial experiments on fruit trees have been carried out at East Malling Research Station (4, 13, 14, 20) during recent years in which the importance of potash for apple-trees, and the necessity for considering the particular requirements of varieties and rootstocks in nutritional investigations, have been clearly established. At this centre the technique of manurial experiments has been closely studied and new experiments are being developed in accordance with the most recent statistical requirements (22).

No outstanding developments have resulted from recent nutritional work on the Continent, but it appears certain from the isolated results (12, 31, 32, 34, 36, 39a) which continue to be obtained that problems associated with potash deficiency will be found of outstanding importance, as has been the general experience in practically every fruit-growing area in this country.

LONG ASHTON INVESTIGATIONS

In the investigations carried out at Long Ashton an attempt has been made to study nutritional problems by laboratory and pot-culture methods in addition to conducting comprehensive field investigations. The main subjects of study may be grouped under the following heads:

(*a*) Effects of deficiencies of the major 'essential' elements of nutrition.

(*b*) The diagnosis of nutritional problems in the field.

(*c*) Materials, soil conditions, and management factors in relation to nutritional conditions.
(*d*) The correlation of nutritional conditions and manurial responses to chemical composition of fruit plants.
(*e*) Pathological conditions—Leaf scorch and chlorosis.
(*f*) Factors determining fruit quality.

Effects of deficiencies of the major 'essential' elements of nutrition.

Deficiency effects have been studied in great detail for the elements nitrogen, potassium, phosphorus, calcium, and magnesium, and to a less extent for sulphur and iron. In the cases of the former group and of sulphur the investigations have been pursued chiefly by means of sand cultures, using chemical solutions as the sole source of supply of the various elements (40, 41, 42). The observations relating to nitrogen and potassium (42, 43–7, 50, 54) have also been partly gained in field studies in instances where deficiencies of the elements have been proved and, in the case of iron deficiency (48, 49, 51), the whole of the facts have been elucidated in connexion with deficiencies of this element in specific cases of lime-induced chlorosis, which subject is discussed in detail in a later section.

The features on which data have generally been collected have been as follows: (1) times of opening of leaf- and blossom-buds; (2) blossom characters; (3) foliage characters throughout the season; (4) shoot growth; (5) defoliation phenomena—relation to time, method and tints developed; (6) condition of barks; (7) yields and characters of fruits; (8) root systems.

The following is a summary of the main deficiency effects which have been observed. For further details and for an account of technique employed in carrying out sand-culture experiments the reader is referred to the following papers (40–2, 54).

Nitrogen deficiency. In pot experiments the omission of nitrogen from nutrient solutions produces deleterious effects more quickly than the omission of any other of the major essential elements, and with young trees under this treatment the growth made during the first season is frequently similar to others receiving a complete starvation diet of 'water only'. The times of opening of blossom- and leaf-buds are delayed, blossom formation is drastically reduced owing to the death of lateral buds, and the flowers are very weak. Foliage is relatively scanty, and after a season or two of the treatment the trees usually only carry foliage at the tips of shoots, thus presenting a characteristic 'bare-wood' appearance. The leaves are relatively small and yellowish green in colour and often develop orange or reddish tints towards the end of the season. Small reddish brown spots may appear on the leaves. Shoot growth is drastically reduced, and after a short period of treatment the trees fail to make appreciable shoot growth. Defoliation is premature and the tints at defoliation time are reddish yellow. The barks become pale brown in colour. Fruiting is quickly reduced to a negligible amount owing to the non-development of lateral buds. Fruits are small, often highly coloured or of chlorotic appearance,

relatively hard in texture, and with high $\frac{\text{sugar}}{\text{nitrogen}}$ ratio. They possess excellent storage qualities both in ordinary and low temperature stores. The root systems are small and in proportion to the amount of shoot growth made, and are composed mainly of fine fibrous rootlets. Nitrogen starvation is of frequent occurrence under grass systems of cultivation and is easily remedied in such cases by cultivation. Trees in low nitrogen conditions react readily to applications of nitrogenous fertilizers.

Potassium deficiency. In pot experiments the effects of potassium deficiency are less drastic than those due to nitrogen omission, but starvation from the former element is a much more serious problem in the field. In sand-culture experiments omission of potassium usually advances the opening of blossom- and leaf-buds, and the blossoms formed are generally strong and normal in appearance. The number of blossom-buds is not drastically decreased as in the case of nitrogen starvation, and indeed may show some increase over completely fed trees, due to the fact that potassium deficiency leads to die-back of shoots, and abnormal development of fruit-buds follows. This condition is often very marked in cases in the field where practically every bud may be a fruit-bud.

During the early part of the season the foliage characters are usually quite normal in appearance, but later, generally from the beginning of June, the special symptoms of the shortage of the element become visible. The colour of the leaves at this stage is often bluish green and there may be slight chlorosis near the margins and between the veins. In some varieties of plum the chlorotic symptoms are strongly marked. In gooseberries the leaves at this stage may show purple tints, but these disappear later. There is often a tendency for the edges of the leaves to curl towards the under surfaces, but, in the case of certain plums, the curling effect is in the reverse direction. The leaf margins finally become brown or grey, following the death of cells in these areas, and have the appearance of having been scorched by fire. This condition is commonly known to fruit-growers as Leaf Scorch and is usually well marked both in pot experiments and in the field by the end of July. This marginal browning may extend inwards between the veins, practically to the midrib, this being usual in the case of the raspberry. Leaf scorch becomes most marked in hot dry summers. In advanced stages of potassium deficiency leaf size is considerably decreased and scorching is less well developed.

In pot experiments shoot growth may be only very slightly affected in the early stages, but eventually it is greatly curtailed and shoots tend to die back, and even whole branches may be thus affected. These latter symptoms are common in the field.

Defoliation from potassium deficiency in the field occurs prematurely, following the development of marginal leaf scorch, and this often happens in pot experiments. Under the latter conditions, however, defoliation may occur later than in the case of 'complete nutrient' trees, the leaves appearing to hang on in a tenacious way. Where defoliation is extremely premature a second

crop of leaves may be developed. During defoliation the colour of the leaves usually turns direct from green to brown, and high tints are generally absent. The method of defoliation is unusual, frequently progressing in the direction from the tips to the bases of the shoots so that the oldest leaves are retained latest. The colour of the barks may be slightly paler than normal.

Fruit yields are greatly reduced in spite of the large number of fruit-buds carried, since, although the buds form blossoms and these set, the fruits formed are very liable to drop and the crop consists almost wholly of culls. After harvest the fruits remain of dull immature appearance; they are sub-acid, often sweet or woody and flavourless, shrivel greatly in store, and frequently are excellent keepers in ordinary temperature stores, but break down prematurely in low temperature stores. Root systems in the field are usually poorly developed, and badly scorched trees frequently feel quite loose when shaken.

Two important practical points relating to potassium deficiency which require mention have emerged from both pot and field experiments, namely, the deficiency appears to promote physiological drought within fruit trees when the environmental conditions are conducive to drying out, and it must usually be considered in relation to the available nitrogen supply to the plants where it occurs. Potassium deficiency is the most serious deficiency 'disease' of fruit-trees in this country, and in the past has been of very frequent occurrence. The field problem is discussed more fully later.

Phosphorus deficiency. The effects of phosphorus starvation of fruit trees in sand cultures after two or three seasons are as severe as, or more severe than, those resulting from nitrogen deficiency, and the features exhibited in the two cases show many points of similarity.

The times of opening of blossom- and leaf-buds are appreciably delayed, and in extreme cases are delayed beyond the times when these occur in comparable trees receiving total starvation diets, i.e. water only. Blossom formation is much reduced, due to the death of lateral buds, and the blossoms are very weak. The foliage exhibits very distinctive characters. The amount is very small, and eventually the only leaves developed are the terminal rosettes. Leaf size is much reduced. It will be evident that the above characters are similar to those due to nitrogen deficiency. In the early spring the leaves are fairly normal in colour, though of rather dull appearance, but they soon become very dull and eventually exhibit characteristic purple and bronzed tints over their entire surfaces, the tinting often being accompanied by the presence of brownish spots, which are pronounced in the case of the black currant. After bronzing, areas of the leaves become dried out.

Trees undergoing phosphorus deficient treatment frequently make excellent growth during the first season, and show little effect from the deficiency—apparently because of the utilization of reserves—but from the second season shoot growth is generally as severely restricted as from nitrogen starvation, and this condition continues from this point. Defoliation is greatly advanced; it may occur in early June and previous to defoliation taking place in trees receiving 'water only' treatment. The barks of the trees are slightly paler than

normal in colour. The yield of fruit is greatly affected and is similar to that which results from nitrogen deficiency, in both cases the reduction being due to dying out of the lateral buds. The colour of the fruits is dull and unattractive, with a suggestion of the bronzing which develops so markedly on the leaves. Unlike low nitrogen fruits, those from phosphorus starvation lack firmness and have no desirable commercial qualities. The root systems are small in proportion to the tops. They often lack fibre and show a characteristic brown colour.

Although phosphorus deficiency in sand cultures produces such drastic effects on fruit trees, no case of proved phosphorus starvation has been observed by us in the field, although cases have been examined on soils which fail to grow pasture plants healthily due to deficiency of the element. It thus appears that the various fruit plants with which we are concerned are good phosphorus feeders.

Calcium deficiency. This treatment has not been observed to produce any effects on the times of opening of blossom- or leaf-buds, and the blossoms which have been developed have always been normal in character. In sand cultures trees receiving diets deficient in calcium usually carry luxuriant foliage in the early stages, the leaves being definitely larger than those in 'complete nutrient' series. This effect is possibly due to 'high' potassium which results, and it has been shown that the large leaves so produced are relatively resistant to water loss under conditions conducive to rapid drying. At a later stage in the treatment leaf size is more normal, and the leaves may show break-down symptoms. In the case of the apple these take the form of patches of dead tissue either near the centres of the leaves or near the margins and, in the latter cases, the brown patches have a reticulated appearance. Similar symptoms result from magnesium deficiency, though in this latter instance the extent of the break-down is much more serious. With plants other than the apple we have not yet been able to produce any consistent and distinctive foliage characters from lack of calcium. In the large leaf stage calcium deficiency is associated with increased shoot growth, and, in our experiments, even after three or four seasons of treatment we have not so far succeeded in effecting significant reductions in shoot growth. Defoliation characters do not show any distinctive features, and the barks are of normal appearance. Nor have distinctive points been observed with regard to fruit characters or root systems. No instance due to calcium deficiency has been observed in the field.

Magnesium deficiency. The times of opening of blossom- and leaf-buds have not been affected by omitting magnesium from the diets of various sorts of trees, and the character of the blossom has always been normal. Very striking effects are produced on the foliage of all fruit plants from a very early stage. In the first stages of magnesium starvation leaf size is inclined to be increased, and usually remains of at least normal size over two or three seasons. In advanced cases, however, the leaves become very dwarfed.

Each class of plant appears to develop a specific type of break-down symptom, and it is necessary to experiment with each to determine the characteristic

features. In the case of the apple the usual symptom is the death of a relatively large patch of tissue near the centre of the leaf around the midrib, and this condition we have termed 'blotch'; but the patches may occur in a haphazard manner on any portion of the leaf, and in some varieties are frequently developed around the margins (*c.v.* calcium deficiency). In the later stages of the deficiency the green colour of the leaf may be slightly pale. In the case of the black currant the central portion of the leaf turns purple, and this coloration develops over practically the whole of the leaf surface until, finally, usually only a narrow marginal band remains green. The leaf at this stage becomes curled towards the under surface. Raspberries and strawberries develop central patches, usually yellow or red tinted, and then similar marginal bands, leaving green, horseshoe-shaped bands between the two tinted areas.

Gooseberries develop broad red marginal bands which gradually spread inwards, becoming paler as they do so.

In all cases of magnesium deficiency, defoliation is premature and follows closely on the development of the break-down symptoms. In advanced cases it may occur very early in the season, when fresh foliage is developed which also becomes affected with the symptoms at an early stage. No effects on the colour of the bark have been noted. Although the trees may blossom normally, the yield of fruit is seriously affected, since the spur leaves often become early affected and the trees carry too little foliage for the development of the fruits, which may consequently remain small and immature specimens. The root systems have generally been well developed and normal in character, but a considerable amount of killing of root fibres has frequently been observed.

No serious cases of magnesium deficiency have been proved in the field, but the leaf characters herein described are frequently observed. In such cases they are possibly due to high potassium conditions, but they also appear to be characteristic of certain varieties and can only be suppressed in these by drastic deficiencies of other elements.

Sulphur deficiency. The observations made relating to sulphur deficiency have been much less extensive than in the previous cases, and the effects of the treatment can be summarized by stating that, in general, they have resembled those resulting from a slightly restricted nitrogen supply. Thus foliage colour is slightly pale green, defoliation has been slightly hastened, and during defoliation brilliant orange tints have been developed. Root systems have appeared normal in character.

Diagnosis of nutritional problems in the field.

Following on the investigations relating to deficiencies, referred to in the previous section, an attempt has been made to apply the results obtained in those experiments to growth problems as they occur under field conditions. The general result has been that the features noted in the sand-culture experiments have been found of great assistance in determining nutritional conditions, but it has been found necessary to apply the results with caution, since experience has shown that the deficiency symptoms may result from

causes other than those which were responsible for them in the pot experiments. The most valuable application of the results to date has been in connexion with the field problem of potassium deficiency, which might have remained unsolved for a considerable period had it not been shown in sand cultures that marginal leaf scorch was a characteristic of potassium deficiency. It has been shown, however, that leaf scorch may result from various causes (6, 37, 45), and in field problems it has been necessary to determine the extent to which various possible causes of the trouble operated in numerous instances. The final conclusion is that the most important factor in the field problem is potassium deficiency.

Similarly, the pot results have been applied to problems of nitrogen supply and have proved of great value in the interpretation of nutritional conditions in relation to this element.

With regard to phosphorus, the chief point which has emerged is that the drastic effects due to phosphorus deficiency which are invariably recorded in sand cultures are not found to exist in the field, and indeed no case of phosphorus deficiency has been proved so far, nor has it been possible to record any significant effect from applications of phosphatic fertilizers in any critical manurial experiment.

Effects due to calcium deficiency would be expected to be most prevalent on strongly acid soils. Such soils are not normally selected for fruit-growing, though in many instances slightly acid soils are utilized. In such instances where unsatisfactory growth has resulted, the symptoms developed have been most frequently those of potassium deficiency and more rarely those of nitrogen starvation, and in all cases these elements when applied have produced the desired responses. Where liming has been tested the treatment has never produced significant growth responses.

The leaf symptoms of magnesium deficiency have proved to be widespread. They often occur on the foliage of strongly growing trees near defoliation time, especially on highly fed nursery stock and in rainy seasons. They also appear to be characteristic of certain varieties under good growth conditions in the different classes of fruits; thus in black currants the characteristic purpling is very marked in the variety Baldwin, and in gooseberries the broad red band is greatly in evidence in several varieties such as Whinham's Industry when growth is healthy, and these are only suppressed when some other deficiency, notably potassium, is acute. A case in which the magnesium deficiency leaf symptoms are strongly developed in association with a serious growth trouble in apples, variety Cox Orange Pippin on Malling No. IX rootstock, is at present under investigation, but it has not been proved so far that the causal factor is deficiency of the element.

Finally, it may be said that the method of using diagnostic symptoms in nutritional problems of trees is well worth developing, and may be expected to prove of value in forestry problems just as it has been found to be useful in fruit-tree investigations. The application of chemical methods to diagnostic work is referred to later in discussing the problems of leaf scorch and chlorosis.

Materials, soil conditions, and management factors in relation to nutritional problems.

Brief reference was made in the introductory section to the necessity of considering various factors relating to materials and environmental conditions in investigating nutritional problems of fruit trees, and some examples of effects due to certain of these were given. In the present section some concrete examples of such effects are recorded which illustrate the magnitude and importance of these effects.

Classes of fruits. In the course of investigations concerning the incidence of potassium deficiency (45), and in carrying out survey work (52) on fruit areas, it has been clearly established that wide differences exist among classes of fruits relative to their resistance to potassium deficiency and to unfavourable soil conditions. A differential response to potash manuring has also been demonstrated at a centre in Kent (47).

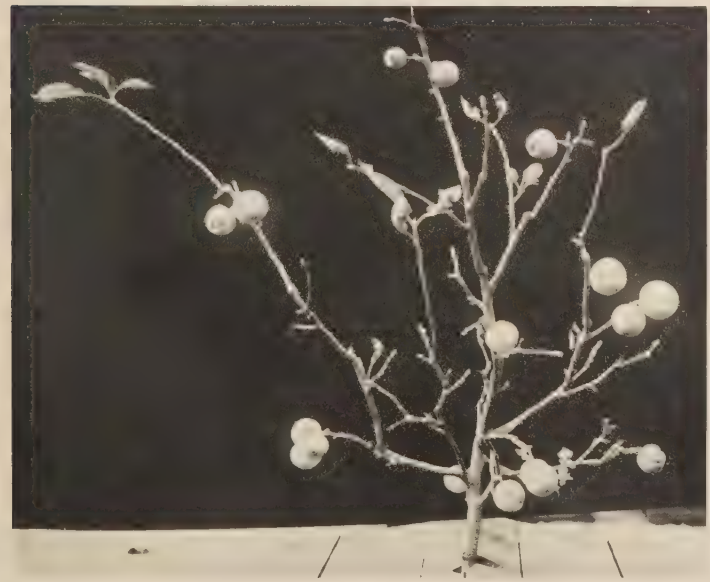
Varieties. Varieties of apples exhibit such wide differences in resistance to potassium deficiency that it has been possible to recommend that certain varieties should not be planted unless an adequate supply of soil potassium is available (45). This is also true of varieties in other classes of fruits, notably of plums (50) and gooseberries (46). An excellent example of differential varietal susceptibility to magnesium starvation is shown in Plate I, where it is seen that the apple variety Bramley's Seedling is much more resistant than Allington Pippin.

Rootstocks. Rootstocks have been shown by East Malling workers to greatly influence the nutritional conditions of fruit trees under varying conditions of soil (19), and that responses to fertilizer treatments may be greatly influenced by this factor (4, 13, 14). The writer has also shown that rootstocks are important in considering problems of potassium deficiency (40, 45, 46), and that they may exert large influences on fruit quality—storage characters and chemical composition (54). Moreover in the latter connexion it is shown that the magnitude of rootstock effect is related to manurial conditions.

Age of tree. The effect of age of tree has been studied by the writer in connexion with problems of storage qualities of fruits (54). The investigations have revealed the facts that fruits from young trees, when compared with those from older trees growing under similar conditions, are always more susceptible to storage maladies—rots and 'break-downs'—and invariably show higher contents of nitrogen and sucrose.

Soil conditions. Detailed soil and pomological surveys have been in progress in commercial fruit areas in this country since 1923 in which attempts have been made to establish correlations between various soil conditions and the growth characters of the different types of fruit trees which are grown. Surveys have already been completed of the Wisbech area (55) and in West Cambridgeshire (as yet unpublished), in East Anglia, and of the Bromyard and Ross-on-Wye areas in the West Midlands (52), while others are still in progress in Kent and in the Evesham and Cheltenham areas. Reference to the published accounts will show that it has been found possible to relate certain soil

Apple tree, variety Bramley's Seedling, growing in quartz sand without magnesium. Photograph during first season of treatment. Note only slight defoliation of terminal shoots (*c.v.* Fig. 2).



Apple tree, variety Allington Pippin, growing in quartz sand without magnesium. Photograph during first season of treatment. The variety is highly susceptible to magnesium deficiency. Note almost total defoliation. (*c.v.* Bramley, a resistant variety, Fig. 1).

PLATE I

conditions with particular types of tree growth and quality of fruits, with definite pathological conditions, and with various economic problems. The two major troubles due to unsuitable soil conditions have been shown to be leaf scorch, due to potassium deficiency, and lime-induced chlorosis, due to iron deficiency associated with calcareous soils. Soil acidity has not proved to be of importance, but physical texture, depth of soil, and water relationships exert profound influences.

Management factors. These factors are of great importance in fruit-growing, and the skilful grower can greatly modify 'natural' effects by various points of management. Thus the nitrogenous conditions within fruit trees can be readily regulated by a judicious combination of cultural methods and the use of nitrogenous fertilizers. Lack of cultivation, with the resultant growth of grass and weeds over the roots of the trees, cuts down the nitrogen content of the trees very drastically, and it has been frequently found in experiments that moderate cultivation is more effective in raising the nitrogen status of trees originally under grass than allowing them to remain in those conditions and relying on annual spring dressings of nitrate of soda at a rate of 5 cwt. per acre to supply the requisite nitrogen (54). Cultural practices also affect potassium requirements. Branch-pruning, bark-ringing, and fruit-thinning are practices widely used by fruit-growers to modify nutritional conditions, and must be taken into account in investigations. Some effects of these practices are recorded in the following references (53, 54).

The correlation of nutritional conditions and manurial responses to chemical composition of fruit plants.

In connexion with the various nutritional investigations carried out at Long Ashton, numerous chemical studies have been carried out with the object of ascertaining the extent to which such studies can help in elucidating nutritional problems.

The manner in which various deficiency treatments are reflected in the mineral contents of various portions of apple trees has been determined in connexion with various pot experiments (9, 41), and chemical determinations have been carried out on a very comprehensive scale in numerous investigations concerning the problems of leaf scorch and chlorosis (44, 46–50). In the deficiency experiments, it has been established that deficiencies of nitrogen, potassium, calcium, magnesium, and phosphorus are reflected in the various portions of the trees by relatively small contents of the respective elements in comparison with amounts present in adequately nourished trees, and by effects on the contents of other elements, and altered contents of total ash and dry matter. Chemical examination was found to provide a means of distinguishing between cases of chlorosis due to potassium deficiency and iron deficiency respectively; where trees representing both troubles occurred on calcareous soil areas (48–50), the leaves of potassium deficient specimens showed relatively high dry matter in fresh weight, low ash in dry matter, and low potash in ash, while those from iron deficient trees showed the reverse

condition for each feature. Chemical composition does not provide a reliable guide to storage properties of fruits (54), but nevertheless chemical features are closely correlated with the effects on fruit quality which result from factors due to materials, environment, and treatment subsequent to picking.

Pathological problems—Leaf scorch and chlorosis.

Leaf scorch and chlorosis have proved to be the two major pathological conditions of fruit trees in this country which are due to defective nutrition.

Leaf scorch. This has formed the subject of extensive investigations of the writer and other workers at Long Ashton, the major publications being the following (6, 27, 37, 43–7, 50). Papers relating to certain phases of the trouble have also been contributed by workers at East Malling Research Station (loc. cit.). The salient features of the disorder are as follows:

It has been of very frequent occurrence in practically every fruit area in the country. The typical symptoms of the trouble, the marginal browning of the leaves, can be produced experimentally in a variety of ways such as deficiency of potassium in the nutrient medium, drying out of the root system, water-logging the root system, damaging the roots extensively, and desiccating the foliage by excessive transpiration. In the field the main cause is potassium deficiency which is often associated with relatively 'high nitrogen' conditions. Although the trouble may occur on all classes of soils, it is found most frequently associated with three conditions: open textured sandy soils with poor water supplies; shallow soils, generally eroded or poorly weathered, often fairly close textured and containing large proportions of fine sand and silt; and heavy soils in wet situations, producing seasonal waterlogging.

The most susceptible classes of fruit plants are apples, gooseberries, red currants, and raspberries, while plums, damsons, cherries, and black currants are on the whole more resistant. Varieties also show a wide range of resistance, and rootstocks exert pronounced influences. Scorching is most prevalent in dry seasons. The trouble is often very difficult to remedy when an advanced case is treated, periods of 3–5 years frequently being necessary to produce observable effects from heavy annual dressings of potash manures, say, sulphate of potash at 3–4 cwt. per acre. 'High' nitrogen conditions aggravate the trouble, and thus low cultivation and withholding of nitrogenous manures tend to mitigate scorching effects.

Chlorosis. By far the most prevalent form of chlorosis falling in the category of nutritional disorders which occurs in fruit areas in this country is that known as lime-induced chlorosis associated with deficiency of iron. A second form which is practically restricted to certain varieties of plum, especially the variety purple Pershore, results from deficiency of potassium (50). Where the latter form is present on calcareous soil areas it can be distinguished from the former type by chemical features of the leaves, as described in the previous section. In investigations at Long Ashton relating to lime-induced chlorosis, attention has been chiefly directed to ascertaining the chemical features of plants

afflicted with the trouble, to determining its incidence in relation to soil conditions, and to evolving practical methods of control. The results of these studies have been reported for the most part in a series of papers by the writer (48, 49, 51). The main points which have emerged are as follows:

The deficiency of iron from which the plants suffer is not clearly reflected by chemical analysis of the leaf and shoot portions of affected parts, but these organs invariably contain relatively low proportions of calcium associated with high proportions of potassium. The pulp of the fruits, on the other hand, shows a content of minerals similar to that in cases of potassium deficiency.

The trouble is only widespread on soils derived from calcareous rocks such as Chalk, Gault, Oolitic Formations, Carboniferous and Dolomitic rocks, and Keuper Marl where 'Skerry' deposits occur, but may be induced by excessive liming such as is frequently practised in private gardens. The incidence of the malady cannot be correlated simply with content of carbonate of lime nor with the reaction of the soil (pH); in some cases it is prevalent where the lime content is approximately 1 per cent. $CaCO_3$, and in other areas the trouble is negligible where the content of this material is greater than 5 per cent.

Attempts to control the 'disease' by treatment with ferrous sulphate, whether added direct to the soil, injected into the trunk, or applied in the form of a spray, have not proved successful from an economic viewpoint. Positive reactions have been obtained by the two latter methods, but the effects have only been temporary and damage has often resulted from their use. Further work on the use of iron salts may, however, be usefully attempted with compounds such as ferric tartrate or citrate, since these appear to keep the iron in active form within the plants at higher pH values than other iron salts.

The most successful method used by us has been to grow cover-crops over the roots of affected trees, and by this means some really striking curative effects have been produced, though the method is not infallible, and may only produce slight improvement in cases where the conditions are extreme owing to soil or fruit materials. The mechanism of the action of cover-crops in ameliorating the chlorotic condition has not been ascertained, but the treatment was first attempted with the idea that local supplies of iron might be rendered available to the trees through the increased production of carbon dioxide in the soil due to the root systems of the cover-crops. Various cover-crops, such as grasses, clovers, lucerne, and weeds from cessation of cultivation, have been tested, and all have produced favourable effects.

Orchard factors determining fruit quality.

The forester is not normally interested in fruit quality problems other than the properties of seeds. For this reason no detailed account of investigations relating to the bearing of nutritional conditions of trees on fruit quality will be given, but it will suffice to mention that nutritional factors greatly affect the qualities of fruits, especially the pulp portions, and that the study of fruit properties affords a further means of assessing the effects of nutritional conditions on tree performance. A summary of the effects on fruit quality of the

more important factors affecting nutritional processes in trees has been published (54).

CONCLUSION

In the foregoing account an attempt has been made to summarize the salient points which have emerged from investigations at Long Ashton relating to the nutritional problems of fruit plants, and brief reference has been made to the main investigations which have been carried out in the past both in this country and abroad and to the trend of recent work at various centres. The account is of necessity of rather a sketchy character, and it is not put forward as an exhaustive digest of the modern position of horticultural research concerning the nutrition of fruit trees. It is hoped, however, that it will serve to introduce workers on forestry problems to the literature relating to the nutrition of fruit plants, and that the results which have been summarized may serve a useful purpose in considering the development of possible lines of work relating to problems which arise in connexion with the nutrition of forest trees.

SUMMARY

1. The objects of investigations relating to the nutrition of fruit trees are briefly stated, and reference is made to the similarities and differences in the problems of the fruit specialist and the forestry expert.

2. The factors which require consideration in nutritional investigations concerning fruit trees are given, and examples are quoted of some general effects due to these.

3. A brief outline of investigations carried out in the past and of more recent studies in this country and abroad is given.

4. The main subjects of investigation relating to problems of fruit-tree nutrition which have been studied at Long Ashton are outlined, and the chief results which have been obtained are summarized, and reference made to the more important publications describing the various investigations.

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MANURING OF FRUIT PLANTATIONS AND ORCHARDS.

Fruit growing in this country is carried out under several distinct systems of farming.

In some cases, the holding is utilised wholly or primarily for intensive fruit culture, when the land is usually mainly occupied by mixed plantations of tree and bush fruits or by unmixed plantations of bush fruits, tree fruits or strawberries. On such farms there is also frequently a small area devoted to grass orcharding. In other cases, fruit farming is practiced in conjunction with market-gardening and the relative importance of the two activities varies in different instances. Again, large areas of fruit are grown on intensive or semi-intensive lines on mixed farms, where considerable proportions of the available acreage may be devoted to stock rearing, milk production, poultry keeping, hop growing, cereal farming, &c. Finally, on numerous farms, especially in the West Midlands and in the South-Western counties, fruit is represented on the farm by the "home orchard" where the produce may be either "market" or cider fruit.

It will be evident from the above considerations that manurial practices will vary greatly under the different farming systems. On farms primarily devoted to fruit production, manurial systems will be especially designed to suit the particular needs of the special fruit crops. In the other cases, the manurial programme will often be determined by the relative importance of the fruit crop in relation to the other products of the farm. Thus in many market gardens, the fruit is of less importance than the interplanted vegetable crops, and the manurial practice is accordingly adapted to the special requirements of the latter crops, whilst in many orchards grazing value is of primary importance, fruit being regarded as a more or less profitable "catch"

crop. It is, of course, outside of the scope of the present article to discuss at length the numerous problems presented by attempting to utilise land for dual purposes such as fruit growing and stock raising or fruit growing and market gardening, but it may be stated that, in certain circumstances, these dual systems may be eminently suitable. A few of the problems which they present in relation to the manuring of the fruit crops are mentioned later in this paper.

It will also be evident, on reflection, that the problems of fruit manuring must differ in many ways from those of ordinary farm crops for reasons such as the following :

In the case of fruit trees, we are concerned with plants which are perennials and which are usually intended to occupy the same land for a long period of years. They must survive periods of very diverse weather conditions during their life histories : they are exposed to cold periods in winter and to hot spells during summer, to drought conditions and excessive wet at various times of the year and to gales which may occur at any season.

The nutritional conditions of trees must therefore be such as to enable them to withstand these diverse climatic influences with a minimum of adverse effects, and thus extremes of nutrient condition must be avoided or serious losses are likely to occur.

The root systems of fruit trees are very large and the roots penetrate much deeper into the soil than do those of the ordinary agricultural crop plants, and thus fruit trees will probably differ in " feeding power " from agricultural plants.

Only one particular portion of the tree is harvested—the fruit—the vegetative portion being allowed to extend its growth for many years, thus becoming relatively large and carrying considerable supplies of reserve food materials.

Moreover, the plants utilised for the production of fruits embrace very divergent types, both as regards their vegetative and fruiting characters, from which it is obvious that the manurial problems relating to the various classes may be expected to show considerable variation.

The above points will suffice to show that the manuring of fruit plants is likely to provide many complicated problems, but there are numerous other factors which render the subject still more complex and which must be considered in any particular case if the best results are to be obtained from manurial treatments.

In order to understand clearly the rôle of manuring in fruit growing, it is necessary to consider the general problem of the nutrition of the various fruit plants which are grown and, in this connection, it is essential to realise, at the outset, that manuring is *only one factor* of the general nutritional problem

and that manurial requirements in any given case are largely dependent on and closely related to other factors.

The major factors concerned in the nutrition of fruit plants may be grouped as follows :—

(*a*) Materials—including the classes of fruits, varieties, root-stocks in the cases of the majority of tree fruits, and the age of the plants.

(*b*) Environmental factors—these include two sub-groups :

1. Natural conditions—including the climatic factors of rainfall, temperature, sunshine ; soil factors, embracing chemical factors, water supply, &c. ; parasitic organisms—pests, fungi, &c.
2. Artificial factors or factors introduced by the grower. These include soil treatment—cultural operations and manuring ; control of pests, fungal and bacterial organisms, &c. ; manual operations on the tree, such as pruning, fruit thinning, bark ringing, &c.

A few examples will suffice to illustrate the interrelationships of manuring to the various other factors involved. Thus plums and black currants as classes require " high " nitrogen conditions ; apples, gooseberries and red currants, on the other hand, have " high " potassium requirements and are susceptible to failure if this element is in poor supply ; varieties and root-stocks behave very differently under certain conditions, some exhibiting strong vegetative tendencies whilst others are precocious and highly fruitful from a very early age, or some may suffer markedly from deficiency diseases where others prove highly resistant and behave in a satisfactory manner ; young plants are naturally relatively " highly nitrogenous," whilst old trees show great need for nitrogenous feeding, and if this need is not supplied, eventually become stagnant ; trees under conditions of high rainfall behave in a similar fashion to trees growing under " high " nitrogen conditions of culture, whilst dry soil locations in wet districts tend to suppress the high rainfall effects ; low cultural conditions also provide a powerful check to factors promoting " high " nitrogen conditions within trees and they may lessen appreciably the effects of potassium deficiency ; pruning operations may produce similar effects to manurial treatment and, whilst manuring may affect the susceptibility of trees to pests and diseases, lack of control of these latter may completely nullify the effects of any manurial applications.

Whilst all these interrelationships must be borne in mind, there are also two further points which require consideration in formulating schemes of manuring fruit plantations and orchards. These are that it must be realised that the manurial requirements

of the trees and bushes are constantly changing throughout the life of the orchard and that manures are applied for special purposes at various stages. With regard to these points, it may be stated that, when a tree is young, the manurial programme is followed with a view to building a sturdy tree which will be capable of carrying good crops of fruit in future years. Thus the immediate object of manuring at that stage is not to mature a fruit crop ; later, the system is primarily directed to the production of successions of crops with special qualities, such as dessert or culinary properties or suitability for cider making.

A little experience in feeding trees shows that these ends are not achieved by any one uniform method of manuring and, indeed, it may be stated that in the case of the apple, with certain varieties, the highest qualities of dessert and culinary fruits can only be obtained by following manurial systems which are widely divergent. Thus the highest dessert quality of the variety Worcester Pearmain is only obtained under relatively low conditions of nitrogen feeding, whilst the best grades of Bramley's Seedling for culinary purposes require relatively high nitrogen conditions for their production.

It will be apparent from the statements above that specific recipes for the manuring of fruit can have little practical value. The only sound basis for the intelligent use of manures on fruit trees is a detailed knowledge of the factors concerned in any particular instance.

To use manures to the best advantage, the farmer must learn to diagnose the nutritional condition of his plants and to assess the relative effects of the various factors which enter into the particular case. Thus he must acquaint himself with the peculiarities as regards nutrition of his various plants, with the effects of the special local conditions of climate and soil and with the reaction of his trees, at various stages, to details of management.

In connection with the first of these points—the peculiarities of his plants—it is worth stressing that, at the present time as the result of recent research, it is possible for farmers to obtain for planting purposes closely standardised trees and bushes of the various types of fruits grown, and that attention to this point in making new plantings will simplify many points of management, including manuring, during the life of the resultant plantations and orchards.

Considerable guidance is now also available on the subjects of diagnosing the nutritional conditions of trees and of the effects of the more important natural environmental factors, such as climate and soil, as they influence tree behaviour in the more important fruit areas in this country, whilst the effects of all the more important management factors on both tree growth

and fruit yield and quality have been closely investigated and the main practical effects of these determined.

Space will not permit of dealing with the details of these questions in the present article, but readers may be referred to the numerous publications of workers at the East Malling and Long Ashton Research Stations dealing with the whole range of these subjects and to the Fruit Soils Surveys publications of the Ministry of Agriculture and Fisheries relating to the special subjects of soil and climatic influences. Moreover, County Horticultural Instructors are now in close touch with the more practical results of the Research Stations and are able to give valuable advice on the various aspects of the problems.

Manurial Experiments on Fruit Crops.

It will be of interest to consider briefly the main investigations which have been carried out in this country on the subject of fruit-tree nutrition, since these illustrate the difficulties of the problem and throw considerable light on the practical problems of manuring.

Prior to 1920, the subject had received scant attention from scientific workers in this country and, indeed, the only investigations of note were those of Bedford and Pickering at Woburn and of Dyer and Shrivell at Hadlow, Kent.

The experiments at Woburn were conducted over a period of twenty-two years on apples, bush fruits and strawberries on two widely different soil types—a heavy clay soil at Ridgmont and a light sandy soil, deficient in potash, at Milbrook.

At the former centre, on apple-trees, both dung at 30 tons and 10 tons per acre and " complete artificials " equivalent in plant food content to 30 tons and 10 tons of dung per acre per annum produced no significant effects either on the growth or fruiting of the trees, whereas large increases were obtained on the same soil from similar treatments, especially with dung, on bush fruits—particularly on gooseberries—whilst vegetable crops and young nursery stock also responded normally to fertilisers on this soil after the removal of the apple trees used in the experiments.

The ploughing in of green crops produced bad effects on this soil.

Although it was realised by Pickering that the results on apples were influenced by the destructive action of spring frosts on the blossom, he formed the opinion that no manurial treatment was likely to be of value for tree fruits such as the apple on soils similar to that at Ridgmont.

Very different results were obtained at the Milbrook Centre. On apples, large increases in crops were obtained both by dung and complete artificials, and it was clearly shown that the major

problem was that of potash deficiency. Similar results were obtained for gooseberries, currants and raspberries, but with strawberries no crop increase followed from any manurial treatment, though dung appeared to prolong the lives of the plants.

In the Hadlow experiments, where apples, plums, gooseberries, currants and strawberries were used, and where the soil is a clay loam overlying a deep bed of heavy clay, crop increases were obtained in all cases from manuring when potash manures were included. The major problem was again demonstrated to be that of potash deficiency.

Since 1920, notable advances have been made on the subject of manurial problems, chiefly at Long Ashton, where the problems have been intensively studied in laboratory, pot culture and field experiments. Workers at East Malling have also made valuable contributions from field experiments. In addition to the work at these Stations, important practical results have been secured on the county council demonstration plots at Hutton, Lancashire; Perdiswell, Worcestershire; and Cannington, Somerset.

At each of the above centres, especially at the two Research Stations, plots containing various classes of fruits are in existence on which striking manurial results can be observed and from which any fruit grower or farmer can learn a great deal which will be useful to him in solving the problems which occur on his own farm.

The nutritional investigations at Long Ashton have been concerned with the following points: the effects of deficiencies of nitrogen, potassium, phosphorus and other elements required by fruit plants to maintain healthy growth; the diagnosis of nutritional problems in the field; the relationships of manuring to materials and environmental factors; and the effects of various factors on yields and qualities of fruits (including culinary and dessert properties, and transport and storage qualities).

The main practical conclusions which may be drawn from the work are as follows:—

Potassium deficiency is the most important manurial problem in practically every commercial fruit growing area in the country, and whilst the deficiency occurs on all types of soils, it is of most frequent occurrence on light soils, on shallow poorly weathered soils of close texture and on heavy soils in wet situations; problems of nitrogenous manuring are highly important for all fruits and especially in connection with the production of dessert and culinary quality; phosphatic manuring does not appear to be of the same importance as potassic and nitrogenous manuring; soil acidity is not a serious problem but highly calcareous soils are often unsuitable for fruit growing, due to chlorosis; grass culture systems induce low nitrogen conditions

in trees ; classes of fruits and varieties have particular manurial requirements and rootstocks may influence manurial problems ; fruit yield and quality may be greatly influenced by manuring with nitrogen and potassium.

At East Malling, the results have also demonstrated the importance of potash for apple-trees on the Research Station type of soil and, in addition, have clearly shown the differential response of varieties and rootstocks to potash manuring.

Effects of Deficiencies of Nitrogen, Phosphorus and Potassium on Fruit Trees.

Nitrogen, phosphorus and potassium constitute the three main fertilising elements of manures applied to fruit plants and it is therefore necessary that growers should be informed of the effects of the elements on the growth features and fruiting processes of the plants. The effects are most easily followed if plants are grown under conditions of deficiency of the respective elements and then the deficient element applied to various nutrient levels. This procedure has been followed at Long Ashton both in controlled pot experiments and on field plots, and in this way the following facts have been established.

Nitrogen Deficiency.—Fruit plants suffer more quickly when subjected to nitrogen starvation than from deficiency of any other element, the plants showing serious effects within one season.

The opening of the blossom and leaf buds is delayed, the blossoms are weak and often die; soon all lateral buds fail to grow and blossom buds are reduced to a minimum. Foliage development becomes greatly restricted and is eventually confined to the tips of weak terminal shoots. The leaves are small, pale yellowish green in colour and may also exhibit reddish tints. Shoot growth practically ceases, the barks become pale brown in colour and the trees are defoliated prematurely, exhibiting at the time of defoliation highly developed, yellow, orange or red tints. Any fruits which are formed remain small and, in " coloured " varieties, are very highly coloured with a red flush, the ground colour, where it remains, being practically white. The flesh of the fruit tends to be white and is hard and crisp and often very sweet though, in the last stages of starvation, sugar development is suppressed and the flesh is rather tasteless and woody. The fruits are long keepers both in a common store and under cold storage conditions. When trees are grown under conditions of low nitrogen, as distinct from drastic nitrogen starvation, then the fruits have valuable dessert properties but are not popular for culinary purposes. If such fruits are produced by this low nitrogen method it is necessary to have regard to the yields obtained *since low nitrogen conditions cut down*

yields in drastic fashion and, in practice, a compromise is usually necessary between yield and quality to obtain the best financial returns.

Phosphorus Deficiency.—The effects of phosphorus deficiency resemble in many ways those due to nitrogen starvation. Thus the opening of blossom and leaf buds is delayed, foliage development is drastically reduced, lateral buds die out almost completely, shoot growth is reduced to a very small amount, leaf size is very small, defoliation is premature and cropping is negligible in amount.

The effects differ from those due to nitrogen deficiency in the following ways : the tints developed on the foliage are of bronze or dull purple shades, the barks remain a duller colour, and the fruits, which are small, are not highly coloured but take on a bronzed hue similar to the characteristic bronzing of the leaves. Nor have the fruits any desirable commercial qualities, being soft and lacking in character. It is usual to find that fruit plants under phosphorus deficiency treatment die earlier than from any other deficiency treatment.

Potassium Deficiency.—This deficiency produces effects which differ markedly from those resulting from deficiencies of nitrogen or phosphorus. The opening of blossom and leaf buds may be hastened and the trees may become well covered with fruit buds whilst shoots die back and even terminal buds eventually become fruit buds. Shoot growth thus becomes greatly restricted or even negligible in amount. Leaf size is decreased and leaf colour is normal in the early part of the year, but later the margins take on a scorched appearance and exhibit the condition known to fruit growers as leaf scorch. In the case of plums, the leaves may also show definite chlorotic symptoms. This is especially evident on the variety Purple Pershore. The barks may be slightly pale, fruits are often abundant but they remain small and may fall prematurely. The harvested crop, at best, consists largely of culls, and the fruits generally retain a dull green, immature appearance, even long after picking time. In ordinary store, many potash deficient fruits keep longer than high potash fruits but, in cold store, they are often susceptible to Low Temperature Breakdown. The fruits also invariably show severe wilting during storage.

Manurial Problems in the Field.

In the early sections of this paper, the complexities of the field problems which arise in connection with the manuring of fruit trees were discussed and examples of the interrelationships which exist between manuring and other nutritional factors were given. It was stated that manuring can only be intelligently carried out when the grower learns to diagnose the nutrient

requirements of his plants and to evaluate the nutritional effects of the various environmental factors which are concerned at any given time. These factors are largely due to climate, soil and management systems. Subsequently, the main findings of nutritional investigations were briefly summarised and it now remains to discuss some of the commoner nutritional problems which arise in practice and the part which manuring plays in these.

The problems selected for discussion are as follows :—

(*a*) Manuring in relation to Grass Cultural Systems.
(*b*) Manurial Problems under Market Garden conditions.
(*c*) The use of Dung and Nitrogenous, Potassic and Phosphatic Fertilisers.
(*d*) The use of Lime.
(*e*) Types of Fertilisers to use.
(*f*) Rates of Application.
(*g*) Time of Application.
(*h*) Manuring in relation to Fruit Quality.

(*a*) *Manuring in relation to Grass Cultural Systems.*

Broadly speaking, it may be said that, in the past, the arable system of fruit growing has been the special method of culture in the Eastern Counties fruit areas whilst grass orcharding has been the popular practice of the Western districts. Sweet cherries in the Eastern areas are, of course, also grown in grass orchards.

The main factor determining the general adoption of the respective systems in the two areas was doubtless that of rainfall, this being relatively low in the east and high in the west.

The nutritional conditions of the trees are very different under the two systems, grass culture effecting drastic nitrogen starvation in the trees and mitigating low potassium effects, whilst cultivation encourages highly nitrogenous growth. For the above reasons, the limiting manurial constituent of trees under grass systems of culture is usually nitrogen and it is only under very exceptional soil conditions that it is found to be otherwise. Now, it has been shown in numerous experiments at Long Ashton that it is extremely difficult to raise the nitrogen content of trees under grass by means of dressings of nitrogenous fertilisers. Thus in many cases annual dressings of nitrate of soda, at a rate of 5 cwt. per acre applied in spring to apple trees under grass, have been less effective in supplying nitrogen to the trees than fairly low cultivation without added nitrogen. It follows from this that cultivation is a cheaper means of supplying nitrogen than nitrogenous fertilisers in cases where substantial responses are necessary and that, if such fertilisers are

to be used on grass to effect significant results, the herbage under the trees will be rendered unfit for stock.

If a grass system of culture is to be adopted, certain points require attention to ensure success, *viz.* :—

A site must be selected which is conducive to vigorous growth, thin dry soils being unsuitable for grass orchard purposes ; strong growing sorts of trees must be used and the orchard must be efficiently stocked and grazed ; if the above conditions cannot be realised, then the grazing value of the herbage must be sacrificed, nitrogenous fertilisers applied in large quantity or occasional cultivation practised.

It should be pointed out that, in grass orchards, much better growth is maintained under pasture conditions than where hay crops are frequently taken.

Where heavy stocking is practised, manuring should generally be given primarily to meet the requirements of the stock, the usual rules of good pasture management being followed.

Poultry and pigs are frequently utilised as means of maintaining an adequate manurial level in grass orchards. The effects produced by poultry are usually excellent and, in many cases, no other fertiliser treatment is necessary, provided the stocking is sufficiently heavy and the usual steps are taken to move the houses, &c. sufficiently often. Where this method is adopted, the rate of stocking and periods of intensive working of small areas must be adjusted in accordance with the appearance of the foliage.

The effects from pigging have frequently been disappointing and the unsatisfactory results have usually been associated with partial nitrogen starvation or with the development of leaf scorch. These two conditions result from under-stocking and over-stocking respectively. Where the former occurs, nitrogenous fertilisers may be applied or some cultivation given and, in the latter case, the stock should be reduced in number or wholly removed and heavy potash dressings applied—say sulphate or muriate of potash at 3 to 4 cwt. per acre or an equivalent rate of potash salts. Moreover, pigs frequently produce very patchy effects in orchards due to uneven stocking and this results in very uneven quality in the fruits, which greatly detracts from the value of the crop.

A system of low cultivation with occasional or semi-grass conditions provides an excellent means of keeping the nitrogen contents of certain types of dessert apples at suitable levels and, in many instances, these cultural conditions, combined with a certain amount of nitrogenous manuring, will be found to be a convenient and economical method of securing satisfactory yields combined with high dessert quality.

Good cider quality is also associated with low nitrogen con-

tent of the fruit and hence the most valuable vintage fruit is obtained from old trees of only moderate vigour under grass orchard conditions.

(*b*) *Manurial Problems under Market Garden Conditions.*

The production of intensive market garden crops necessitates a very high level of manuring and, in particular, nitrogenous manures must be applied in quantities far above the rates required for ordinary arable farm crops. If the various vegetable crops are taken as intercrops between fruit tree rows, it is impossible to maintain separate fertiliser levels for the trees and the interplanted ground crops and, in such cases, the trees are invariably subjected to conditions *above* the optimum level of nutrition to secure the best results. In certain cases, the excessively high nitrogenous conditions seriously affect the growth and health of the trees, sometimes leading to extremely vigorous, unfruitful trees or resulting in stunted and useless leaf-scorched specimens. The latter effect is generally more pronounced on lighter soil areas. The fundamental trouble is the excessively high nitrogenous conditions, and the most profitable method of minimising the effect without lowering the productivity of the vegetable crops is to plant classes and varieties of trees which are best able to stand the conditions and which also yield desirable types of produce under the circumstances. The abnormal nitrogen conditions cannot be countered successfully by any manurial method, although the adequate use of potash manures may serve to prevent stunting and leaf scorch in the trees.

The most suitable class of tree fruit to grow in conjunction with highly manured market garden crops is undoubtedly the plum, which requires plentiful supplies of nitrogen to maintain vigorous growth and for the production of high quality produce. In the most extreme cases " coloured " plums usually fare better than " yellow " varieties, though the variety Purple Pershore is an exception, being highly susceptible to potassium deficiency. If special advantages are to be gained from growing apples in market garden areas, then, on highly manured land, the varieties should normally be restricted to culinary sorts, since the conditions are unfavourable to the production of the highest dessert quality.

Market garden conditions on the whole are suited to soft fruit production, but potash deficiency must be guarded against in gooseberries and red currants and, in some cases, the high nitrogen conditions lead to excessive cane formation in raspberries.

It is perhaps necessary to mention that the various fruits from highly worked market garden areas, as a class, possess relatively poor keeping qualities.

(*c*) *The use of Dung and Nitrogenous, Potassic and Phosphatic Fertilisers.*

In experiments carried out on bush fruits by various investigators, it has been usual to find that dung has proved more efficient in producing growth and maintaining high yields of fruit than any system depending solely on the action of fertilisers for supplying amounts of nitrogen, phosphorus and potassium comparable to those contained in the dung. These results are in agreement with the general concensus of opinion among practical growers and the high value of dung for soft fruits can be regarded as well established by experiment and practice. Dung also appears to exert a favourable effect on the longevity of these classes of fruit plants.

In the case of tree fruits, dung is usually very valuable for stone fruits such as plums, but for fruits such as apples and pears, where keeping quality and firmness are of great importance, it must be used with caution or unfavourable effects may result. Dung has been proved to be an effective source of potash in several severe cases of leaf scorch and its use in cases of this trouble on heavy soils may be strongly recommended.

Nitrogenous fertilisers are of great value for all classes of fruits in a variety of situations, but it is necessary to study the effects in particular cases very closely and to observe carefully three points, the growth features of the trees, the yields of fruits and the quality characters of the fruits. They generally produce increased yields on bush fruits, stone fruits and pears but less consistently on apples grown under arable conditions. Under systems of grass culture, or "low" cultural conditions, nitrogenous fertilisers usually produce marked results on growth and cropping of all classes of tree fruits, but it will often be found that similar or greater increases will be obtained more cheaply by adopting systems of higher cultivation, and this point will frequently require consideration, especially in apple culture, where an elastic cultural system is frequently desirable.

Where fruit production is greatly increased from nitrogenous manuring, quality is generally appreciably altered. In the case of the apple, red colour is usually greatly decreased and may be almost eliminated, the fruits are softer, more liable to bruise, become relatively poor keepers and are more suited for culinary than for dessert purposes.

Attempts to raise production to excessive heights by means of nitrogenous fertilisers may drive the trees into excessive wood growth, when fruiting may be drastically reduced, fruit size decreased and the tree become affected with nutritional disorders such as leaf scorch or diseases such as scab, canker and die-back.

In cases of potassium deficiency, it is always advisable to

withhold nitrogenous manures since the application of such materials merely serves to aggravate the deficiency. Excellent examples of such cases can be seen on the Research Station plots at Long Ashton. Since potassium deficiency is of such common occurrence in the fruit areas of this country, it is accordingly necessary to use nitrogenous fertilisers on fruits with caution and previously to ensure adequate potash supplies.

Owing to the widespread occurrence of potash deficiency of fruit trees in our large commercial fruit areas, the practical problems relating to the trouble have been much investigated during the past decade and, as a result, much knowledge has been gained relating to the field factors concerned in the deficiency and to the general effects of potash manures on fruit plants. The deficiency is popularly known as " Leaf Scorch " and is the most serious nutritional trouble of fruit trees with which fruit growers have to contend.

It has been shown that serious cases of the deficiency may occur in fruit plants on soils on which ordinary agricultural plants do not normally respond to potassic fertilisers and observations suggest that, with certain classes of fruits (and with particular varieties) such as apples, gooseberries and red currants, an adequate potash supply in the soil should be provided by manuring, even on clay soils, by means of regular dressings of potash manures. Annual dressings of potash fertilisers equivalent to 1 to 2 cwt. per acre of sulphate of potash will usually be adequate to maintain the necessary potash supply, but where extreme deficiencies occur, causing stunting, failure and die-back, then annual dressings at rates of 3 or 4 cwt. per acre may be required over a period of three to five years to restore healthy growth. The great difficulty of restoring potash-starved trees to normal healthy conditions requires stressing since anyone not familiar with the trouble could be excused for not persevering with the potash treatment in many cases, as visible improvement is frequently not observed until two or three seasons of treatment have been given. The slow action of potash manures on fruit trees, with the consequent failure to observe results, no doubt accounts to some extent for the prevalence of the deficiency effects of the element, but comparison with other important fruit growing areas in the world, such as Canada and the U.S.A., also leads to the conclusion that the special climatic conditions which exist in this country increase the requirements of our fruit plants for potassium.

In the section dealing with phosphorus deficiency, it was shown that the effects of starvation from this element are extremely drastic. Experience in the field, however, has failed to show that fruit plants in the important areas in this country ever exhibit symptoms of the deficiency. Cases are known where

agricultural crop plants, pasture plants, &c., fail to make healthy growth on certain soil areas due to phosphorus starvation but where fruit plants of various types flourish without added supplies of phosphatic materials. Although serious cases of the deficiency have not been observed, it has not yet been established that fruit does not generally benefit from applications of phosphates and, until further knowledge has been acquired, it seems safest to apply phosphates in moderate amounts. There does not appear to be any advantage to be gained from applying heavy dressings of phosphates as has been the almost universal practice of fruit growers in the past.

(*d*) *The Use of Lime.*

Lime has been a popular "manure" in many fruit areas, especially for stone fruits such as cherries and plums, for which fruits lime is generally regarded as necessary for stone formation. There are, however, no critical data to substantiate this point and the idea seems to have grown from the special suitability of certain calcareous soils for such fruits. No critical experiment in this country has ever shown that "liming" is beneficial to fruits on the classes of soils utilised for fruit growing though, on the other hand, many cases are known where calcareous soils are unsuitable for fruit growing, due to high lime content resulting in the development of lime-induced chlorosis. Observation shows that various fruit plants utilised in this country thrive on slightly acid soils, and it has been the writer's experience that where poor results have been obtained with fruit on acid soils, liming has had negative effects, whereas favourable responses have followed from applications of potash fertilisers.

(*e*) *Types of Fertilisers to Use.*

In the past, the so-called "organic" manures such as shoddy, hoof and horn, meat meals, guano, &c., have been held in high esteem as fertilisers by fruit growers, who have regarded inorganic materials such as nitrate of soda, sulphate of ammonia, superphosphate, &c., either as inferior to the former group in action or as producing positively deleterious effects on the various fruit plants.

There are certain special circumstances which have doubtless been mainly responsible for the formulation of these views. In the first place, fruit growing is frequently combined with market-gardening activities for which ample supplies of soil humus are necessary and, since adequate amounts of dung are not procurable, growers have relied mainly on types of organic materials regarded as contributing to the maintenance of humus content. Secondly, the opinion is widely held that fruit plants require a continuous source of food supply over the growing season and

it is thought that this will only be possible from slowly decomposing organic residues. Inorganic fertilisers, containing readily available forms of nitrogen and phosphorus, are regarded as exercising stimulating effects as distinct from normal feeding action. Lastly, it is quite easy to demonstrate how easily injury may ensue from excessive or carelessly applied dressings of the majority of inorganic fertilisers and hence in practice it is easier to use "organics."

There is no critical evidence from which the conclusion may be drawn that organic materials are superior to inorganic fertilisers as sources of plant foods for fruit plants though it might be expected that bulky, hygroscopic materials, such as shoddy, would prove superior to inorganic nitrogenous fertilisers in the case of bush fruits and strawberries, in which cases soil moisture conditions are of such tremendous importance during the fruiting period, and for which reason, where the organic matter content of the soil is low, such materials are to be recommended. In the case of tree fruits, numerous experiments have been conducted in America in which organic and inorganic forms of nitrogen have been compared, mainly on apple trees, and the results have been very definitely in favour of the inorganic forms and especially under systems of low cultivation where nitrogen is most required. No differences have yet been noted in similar experiments at Long Ashton on apples under clean cultivation.

In this country, the form of potash fertiliser to use is of importance. Numerous cases have been reported and observed where serious damage has followed the use of muriate of potash, potash salts and kainit on bush fruits. In such cases, where the injured plants have subsequently recovered, the applications have generally exercised beneficial potash effects from which it may be concluded that the damage is caused by the chlorides in the fertilisers. For this reason, sulphate of potash is recommended for soft fruits and strawberries and this material may be applied without any special precautions. For tree fruits, any potash fertiliser containing a high percentage of potash may be used, but kainit is not recommended owing to the heavy dressings often required in severe cases of potash deficiency and the bad effects on tilth which follow the use of this fertiliser.

(*f*) *Rates of Application.*

It is not possible to recommend rates of manurial dressings for general use on fruit plants, since the amounts required depend on the particular circumstances at any given time in each individual case. In deciding rates to apply, guidance must be sought from the appearance of the plants, previous experience of responses to dressings of fertilisers, points of management

premeditated for the season in question, previous cropping and the probability of cropping or the amount of crop actually developing at the time.

Certain general statements, however, can be made relating to the general requirements of certain classes of plants for nitrogen and potash though, again, it is necessary to bear in mind the individual requirements of varieties and the modifying influences of rootstocks. Plants such as the plum and the black currant are gross nitrogen feeders and also require general nutritional conditions to be at a high level. This is probably also true of cherries, though to a less extent. With other fruits, such as the apple, gooseberry, raspberry and strawberry, care must be exercised in practising high feeding since unfavourable results such as excessive growth, liability to disease or undesirable quality of fruit may occur. In the cases of the apple, gooseberry and red currant, it is also necessary to ensure adequate potash supplies before nitrogen is given in quantity. Reference has previously been made to the rates of applying potash manures under various circumstances.

(*g*) *Time of Application.*

This subject has been much discussed in the past and still requires much investigation before it will be possible to pronounce with authority on many points.

It is often stated that spring manuring of tree fruits produces vegetative growth, whilst late summer and autumn fertiliser applications induce fruitfulness and feed the developing fruit buds. It is well established that fruit plants normally make the greater portion of their annual shoot growth in the spring and early summer and lay down fruit buds in late summer or early autumn for the production of fruit in the following year, but it does not follow because of this cycle that manuring in the spring will not be efficacious in producing fruit buds or that manuring at the time of fruit bud formation will be particularly effective in forwarding this process. The storage of carbohydrate materials appears to be the important feature in fruit-bud formation and it is a little difficult to see how this process can be substantially aided by the application of fertilisers at the critical period. Nitrogen is perhaps the only element which is likely to enter the plant at all quickly after application under field conditions, even when climatic conditions are favourable for the prompt intake of the material, and it seems likely, according to current views, that accumulation of this element in quantity within the plant may hinder rather than help carbohydrate storage. Potash applications are not quickly utilised by fruit trees as has been previously mentioned, possibly due to soil absorption processes, whilst in the case of phosphorus it has not

as yet been possible to demonstrate that any favourable responses are ever obtained from applications of this element in the field.

In experiments at Long Ashton where both " nitrogen only " and " complete fertilisers " containing nitrogen, phosphorus and potassium have been applied annually to apple-trees under cultivation in March, June and August respectively since 1920, no difference in growth or cropping due to time of application has been evident, but all treatments have effected similar responses over the control " no manure " treatment. All treatments have also failed to influence biennial bearing in the variety Allington Pippin. In America, it is claimed that the application of quick-acting nitrogen fertilisers, such as nitrate of soda or sulphate of ammonia, to apples just previous to the blossoming period increases the " set " of fruit. In plants such as the black currant and raspberry, which fruit mainly and entirely respectively on shoots made in the previous season, it would be expected that greater effects would be obtained from manurial treatments which produce the greatest wood growth and this would be expected from early spring dressings since the bulk of new shoot growth is made before midsummer. It will thus be evident that, at the present time, there is no evidence to show that early spring applications of fertilisers are not the best for the various classes of fruit plants.

(*h*) *Manuring in Relation to Fruit Quality.*

Quality in fruits is a very important aspect of the various crops and the best economic results cannot be obtained unless the subject receives the very careful attention of the grower. Quality may be varied by many practices, for example by cultivation, pruning, spraying and bark ringing, so that manuring must be considered in relation to these.

To understand the nature of the effects which manures can exercise on quality, it is necessary to know the characteristic effects of differential supplies of nitrogen, phosphorus and potassium on fruits.

The principal effects have been summarised in the section describing deficiencies, and perhaps the main point which requires further stressing here is the great importance of nitrogen and potassium in practice. The simplest way to ensure suitable quality is first to see that potassium supplies in the soil are adequate and then to vary the nitrogenous level in the fruits by manurial or other methods. It will always be found that quality can be altered very quickly by changed nitrogen conditions and growers should use this fact to the best advantage. In this connection, further mention is necessary regarding the points that low nitrogen conditions, although perhaps giving the

best quality of certain dessert fruits, usually mean *lowered* yields, whilst above a certain level of nitrogenous feeding, both yields and quality fall off. The largest specimens of fruits are not obtained under the highest nitrogen conditions but under conditions most favourable to carbohydrate storage within the fruits and where, in addition, nitrogen is not a limiting factor to growth processes. These conditions are within the range of the extremely high and low levels of nitrogenous feeding under which fruit trees will thrive and must be determined by experience in particular cases.

Conclusion.

The present article will achieve its object if it serves to demonstrate to growers the highly specialised character of the problems involved in manuring fruit and to provide a basis for approaching nutritional problems of fruit trees in accordance with present knowledge. All operations in fruit growing are highly technical, but the routine of the fruit farm can usually be considerably simplified and results improved if the principles underlying the various operations are understood and the effects on the trees of various factors which are introduced can be interpretated in terms of vegetative growth and of fruit yields and quality.

It is impracticable to lay down hard and fast rules regarding manuring or any other practice. There is no best method of manuring which can be categorically stated to serve for all time, even for a particular plantation, and the desired results can only be achieved by keeping a constant watch on the fruit plants and applying the necessary treatments according to the principles laid down in this paper, coupled with the results of past experiences.

Much still remains to be learned of the effects of manures on fruit plants, but the present knowledge, if applied in a rational way, is capable of producing considerable effects on the economics of fruit farming.

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